Sir Charles Wheatstone did not actually invent the famous bridge circuit that perpetuates his name in technical lore and literature, but he did make many other important contributions to the technology. The present article outlines the life of this man of many talents and interests, with emphasis on his career as an inventor and scientist.

Portrait from *The Illustrated London News*, vol. 67, p. 459 (1875). Photographic copy courtesy of General Aniline & Film Corporation.

Except, perhaps, for the well-known bridge circuit that bears his name—and which, paradoxically, was not his creation—Sir Charles Wheatstone is little remembered today. However, in his lifetime (1802–1875) he enjoyed a considerable amount of acclaim, and associated with the leading scholars, artists, statesmen, and industrialists of Victorian England—and, although his fame has not endured, many of his contributions to science and technology have.

Beginning of a career

Charles Wheatstone was born in Gloucester, England, in 1802, moving to London with his family when he was four years old. He was a precocious child, having learned to read while still at Gloucester, and he attended private schools in London until he was about 14. He then was apprenticed to a namesake uncle who manufactured musical instruments. Young Charles showed little promise at learning the trade, preferring to go off by himself to read books instead of pursuing his assigned tasks, but his uncle apparently accepted this in good grace, and Charles' father, an accomplished musician and something of a scholar, permitted Charles to devote three years to independent studies in science, literature, and languages. His subsequent achievements show that he had the necessary powers of concentration and self-discipline to profit greatly from such an opportunity. With his studies behind him, Wheatstone returned to the musical instrument shop and in a short time was conducting experimental investigations in acoustics. As an authority on acoustics and music theory, he was more of an asset to his uncle's business than he would have been had he successfully continued in his initial role as an apprentice.

One demonstration, first conducted by Wheatstone in 1821 and repeated later with variations, that attracted a great deal of attention, featured two musical instruments. The two instruments appeared to be decoupled, being in separate rooms of a building, but actually they were very strongly coupled by means of a taut metal wire, or thin rod, that connected their resonant chambers, or sounding boards. When one instrument was played, sound was conducted to the other through the metal conductor, and deceptive sensations were experienced by the onlookers, who saw only one instrument but heard a duet. Various instruments were used—pianos, harps, lyres, guitar—sometimes two of a kind, sometimes two different instruments. The first experiments featured antique lyres. A lyre used in this manner was popularly called an "enchanted lyre," and Wheatstone also used this term to designate the class of demonstrations that he developed from the experiments.

Another of Wheatstone's experiments involved the "kaleidophone," a name he coined for a vibrating rod clamped at one end. There were several forms of the kaleidophone—steel rods with variations both as to cross section and linear shape, with one or more silvered glass beads mounted on the ends. When a rod was excited into oscillations, the motion of the glass bead (or beads) on its free end presented a pattern to the eye through the persistence of visual perception.[1]

In this period Wheatstone wrote a number of papers on the transmission of sound, the sympathetic vibrations induced in acoustic resonators, and the fundamentals of harmony. Between the ages of 17 and 26 he also carried out studies to relate the loudness of music to amplitude of vibration and the quality of musical tone to harmonic content. Although they were not as fundamental and important as his later studies, they were of sufficient interest to earn him a reputation as an outstanding young scientist.

When Wheatstone was only 21, his ten-page monograph, "New Experiments in Sound," was read to the Academy of Sciences in Paris by M. Arago, and it was published in Thomson's *Annals of Philosophy* in 1823 and reprinted in leading French and German journals the same year. At about the same time, the celebrated Professor Oersted of Copenhagen came to the Wheatstone music shop to meet Charles and witness his experiments.

Some practical devices

Although Wheatstone had a keen interest in scientific principles, he also maintained an appreciation for the practical utilization of science, and whether he was pursuing an abstract idea or inventing a new gadget, he displayed a rare ingenuity for combining mechanical skill with an understanding of physical and mathematical principles.

By the time he was 34, Wheatstone had begun to investigate the problems and possibilities of submarine telegraphy.[2] Four years later he completed what he felt

Sir Charles Wheatstone—forgotten genius

Although the results of Wheatstone's scientific work have endured; his personal fame has not. However, during his lifetime he enjoyed a reputation as one of the leading scientists of the period

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were satisfactory design studies, and was ready to discuss, before the Railway Committee of the House of Commons, the practicability of installing a submarine line between Dover, England, and Calais, France. Following the development of a prototype model of a land telegraph system between Camden Town and Euston Station (purported to be accomplished in collaboration with Cooke) which he demonstrated for the Prince Consort in 1843, he was able to demonstrate submarine telegraphy in an 1844 experiment in Swansea Bay during which he transmitted signals by telegraph between a boat and Mumbles Lighthouse.[3]

Measurements of time were a preoccupation with Wheatstone. He invented an electromagnetic clock[4] in 1840 and another clock (1848) that used the polarization of skylight to determine the solar time; its advantage over the ordinary sundial was that it could be used on a cloudy day.

The articulation of human speech was another subject that received his attention, and he went so far as to construct a speaking machine after the descriptions of de Kempelen.[4] A study on the physiology of vision, which he carried out in 1838, resulted in the invention of the stereoscope.

In all, Wheatstone's ingenuity is evidenced by his invention of more than 140 automatic instruments, devices that he lived to see put into use.

Professor Wheatstone of King's College

When placed in proper perspective, Wheatstone's early studies on the kaleidophone became important extensions of the work of Chladni, and it was probably through having conducted them that he was able later, at the age of 31, to perform a detailed theoretical analysis of the Chladni figures, showing them to be a superposition of normal modes.[4] When he was only 32, he was appointed a professor of experimental philosophy at King's College in London, and two years later was elected a Fellow of the Royal Society.

Within a year after receiving his King's College appointment, Wheatstone reported an experimental study that had important consequences, in spite of his failure, and that of others, to interpret the results. Posing the objective of measuring the speed of propagation of an electromagnetic impulse along a conductor, Wheatstone invented a method whereby a rotating mirror was used to observe the timing of sparks across three closely spaced gaps, inserted at the middle and both ends of a 0.8-km length of wire mounted on an insulating frame in the Gallery in Adelaide Street, King's College. This instrument had a resolving time of less than one microsecond.[4] Its attainable accuracy should have been at least one part in 1000 in principle, because the speed of rotation of the mirror was determined by the pitch of a musical tone created by the rotation, and the measurement of frequency by this method by one with Wheatstone's knowledge of music and acoustics should have been that precise. (It is interesting to note that he considered a modification of this instrument to be used as a stroboscope, an idea implicit in his writings and unpublished notes.[2]) The velocity of propagation in this case was measured with great accuracy, and turned out to be about 1.5 times the velocity of light *in vacuo*. The coupling of the wires given by the particular geometric arrangement determined the velocity as a special case that could not be treated by electromagnetic theory as it stood then. Fifteen years later, Fizeau used a variation of Wheatstone's rotating mirror to measure the velocity of light.

Wheatstone also carried out two other important experiments in his first year as a faculty member at King's College. Although Wollaston, Bunsen, and Fraunhofer had discovered lines in the emission spectra of elements, it was Wheatstone who demonstrated that these lines could be used as a specific means for chemical identification, and he did this by utilizing the spark spectrum of various metals.[4] His other experiment verified Bernoulli's theory of the sound vibrations of a pipe open at both ends, i.e., "that in the fundamental sound of a tube, open at both ends, the portions of air on opposite sides of the center of the tube move in opposite directions to each other." A flexible open cylindrical tube was excited into sympathetic vibrations by a plate made to oscillate in its fun-

damental mode either by stroking with a violin bow or striking with a hammer. The opposite ends of the tube were first arranged so that the vibrations of the plate were exactly out of phase at the two ends; no augmentation of the original sound was heard. The ends then were rearranged so that the plate vibrated at both ends exactly in phase—and the augmentation of sound was quite evident.[4]

In 1843 Wheatstone accepted an invitation from the Royal Society of London to deliver the annual Bakerian lecture. He chose as his title, "An Account of Several New Instruments and Processes for Determining the Constants of a Voltaic Circuit." While looking into the feasibility of telegraphy, by studying the behavior of electric circuits extended over great distances, he had employed a variety of methods to determine the interrelationships between current, voltage, and resistance. Although the basic methods were not new, Wheatstone had added his own refinements. He summarized these experimental methods in his Bakerian lecture, which was a review embellished by the presentation of some new details. Wheatstone cited several investigators who had confirmed Ohm's law—Fechner, Lenz, and Pouillet. In describing rheostats of his own design, Wheatstone mentioned that similar devices had also been used by Jacobi and Poggendorff. Wheatstone's methods were of two types: (1) the substitution method, in which the deflection of a galvanometer was made the same by adjusting a calibrated rheostat which replaced an unknown resistance; and (2) the differential method, in which a null reading on a galvanometer was produced by adjusting a calibrated rheostat.

A decade earlier the Bakerian lecture had been given by Samuel Hunter Christie (1784–1865), F.R.S., who was born in London and was a member of the mathematics faculty (1806–1854) at the Royal Military Academy at Woolwich (a suburb of London). In his lecture Christie described his experimental studies to determine the relative conducting power of a number of metallic elements. He made no reference to the work of Ohm, but he did refer to the studies of Davy, Becquerel, Cummings, and Harris. Whereas Davy and Becquerel had studied the conducting power of metals by using voltaic piles, Cummings had used thermoelectricity, Harris had used electricity from a "machine," and Christie employed a new effect discovered by Faraday—current induced by a magnet. Christie used two differential circuits, which were described in Wheatstone's Bakerian lecture ten years later. One of these differential circuits has become known as the "Wheatstone bridge." Whereas Christie determined the relative conducting power of certain metals with the bridge circuit, Wheatstone exploited the capabilities of the bridge to determine resistance, and since he set the precedent for using the bridge in the way in which it has since been used, it is understandable that in time it came to bear his name. Wheatstone did not cite Christie in the transcript of the Bakerian lecture that appeared in the *Philosophical Transactions*. Apparently Christie's prior work was brought to his attention later. He then added a footnote to his file copy giving full credit to Christie, and this appears in the version of the Bakerian lecture contained in his collected papers.[3,4]

Wheatstone, the man

Charles Wheatstone was diffident by nature, and lecturing was a burden that he was never able to carry effectively. He rarely gave formal lectures, even at King's College, where his activities centered about research. Nevertheless, in a small gathering, among those who shared his numerous interests, he was considered a brilliant conversationalist. He was methodical, quiet in a crowd, but articulate and excitable among intimate acquaintances. He enjoyed lifelong friendships, and his domestic life was said to be tranquil. Although he was mild mannered in his dealings, it was not through an inability to uphold his convictions. He was sometimes mulishly dogmatic, as on the occasion when, refereeing for the Royal Society, he rejected Joule's paper that established the first law of thermodynamics. Furthermore, he could be ungracious; in 1867 he refused the Albert Medal of the Royal Society of Arts because the same award had been offered to Cooke. Thus, quite a range of characteristics were attributed to Wheatstone, as might be expected for a complex man of genius.

During his career, Wheatstone served on a number of important committees of government and industry. He was appointed to the Board of Trade Committee on The Atlantic Cable[1] in 1859, he became a member of the board of directors of the Universal Private Telegraph Company[5] in 1863, and he served on the Scientific Committee of the Atlantic Telegraph Company[6] in 1864. He also served on the Ordnance Select Committee of the British government.[7] In recognition of Wheatstone's many services, he was knighted in 1868 by the government of Lord Derby.[1]

He received medals from the Royal Society in 1840 and 1843,[1] and was awarded honorary doctorates by Oxford University (1862), Cambridge University (1864), and Edinburgh University (1869). He was made a Chevalier of the French Legion of Honor in 1855,[8,9] and an honorary member of the Italian Society of Sciences in 1867.[1] In 1873 he was made a Foreign Associate of the Academy of Science (France),[8,9] and awarded the Ampère Medal by the French Society for the Encouragement of National Industry. In 1875 he was elected an honorary member of the Institution of Civil Engineers.[3]

In spite of his relative lack of fame today, Wheatstone's life was a successful and productive one. His papers, and the scientific instruments he bequeathed to King's College, reveal his mastery of invention and experimentation, his skill in reducing a problem to its essential parts, and his flair for designing simple instruments to probe the ways of nature.

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